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Gas-Filled Discharge Tubes as Light Sources for High Speed Photography

By J. W. MITCHELL, M.Sc., D.Phil.

Summary

This paper describes the development of high-intensity flash discharge tubes capable of giving light flashes with an effective photographic duration of less than 1.5 microseconds, which can be used for photographing high-velocity shells by reflected light. The properties and the limitations of flash discharge tubes in single flash and in multiple flash applications are discussed.

Introduction

Photographic methods have to be used for studying a wide range of events in which changes occur too rapidly for the eye to appreciate the shapes, surface details, relative positions and movements of the objects involved. There are two principal techniques, the details depending on whether single photographs, sequences of photographs, or continuous ciné-records are required: for the first, the subject is illuminated with arc lamps, tungsten filament projection lamps, or even long duration pyrotechnic flashes, and the photographs are taken on stationary film in cameras fitted with high-speed mechanical shutters, or on moving film in cameras with optical compensation; for the second, shutters are unnecessary, as illumination is provided by short duration flashes with high peak intensities.[1, 2] In the high-speed ciné-cameras, the film is moved continuously behind a fixed slit, whose width can be varied, and the optical system is designed to keep the image stationary with respect to the moving film.[3] As with the focal plane shutter, the exposure is determined by the width of the slit, the minimum practical width decreasing as the illumination is increased. The Vinten H.S.3000 camera is an example; in it 48 lenses, with axes separated by the normal frame separation of 35 mm. film, are mounted in a ring near the edge of a rotating circular drum. At a linear speed equal to the tangential speed of the rotating lenses, the film is moved round another drum whose forward surface lies in the focal plane of the lenses. The lens ring and the film drum have their axes at right angles, and are driven through gear trains from the same motor. The slit lies approximately in the focal plane of the lenses. The principle is the same as in a camera with a focal plane shutter, but lens and film are moved at the same high speed, while the slit remains stationary. The camera operates reliably up to 1,500 frames per second, and by using a narrow slit, good definition can be obtained. The accurate spacing of successive frames is ensured by the mechanical design.

Where applicable, the second method has certain advantages: optical compensation systems and shutters are not required; the images are practically free from the image distortion which is inevitably associated with optical compensation of the type described; there is a great economy of power because energy is converted only during the actual exposure; and on account of the high peak intensities of the light flashes, much shorter exposures are possible. These short duration flash methods give excellent results for single photograph

Dr. Mitchell is at the H. H. Wills Physical Laboratory, University of Bristol. The MS. of this paper was first received on July 24, 1948, and in its revised form on September 30, 1948.

work. The results are less satisfactory when sequences are taken, using a high-speed drum camera to separate the successive photographs; and many problems remain to be solved before they can be used reliably for ciné-photography at rates above a few hundred frames per second. The design and construction, properties and limitations, of the short duration light sources used for these methods will be considered in this paper, which is based mainly on experimental work carried out between 1943 and 1945, when the author was a member of the staff of the Armament Research Department of the Ministry of Supply. Many of the conclusions are qualitative or, at most, semi-quantitative, because a thorough systematic investigation was not undertaken. Despite this limitation, it seems desirable to publish a record of this war-time experience.

High-speed photography, with exposures of a few millionths of a second, determined by the duration of the light flashes produced with gas-filled discharge tubes, requires only an ordinary photographic camera. Stereoscopic pairs can be taken with a stereoscopic camera, and, when printed and viewed through a stereoscope, they give a vivid spatial representation. The methods have been applied in a wide range of investigations, including: the flight of birds and insects and the behaviour of small insectivorous animals, relatively high-power photomicrography with living organisms; in aerodynamics, shock waves and vortex sheets in supersonic streams; liquid jet phenomena, including droplet and spray formation; fracture in glass, metals and plastics; high-speed rotating and reciprocating mechanisms, and many problems of armaments research, particularly the photography of high-speed projectiles by reflected light.

The Design and Properties of Discharge Tubes for High-Speed Photography

In these methods of flash photography, the electrical energy, part of which is converted into light energy, is stored in a high voltage condenser which is charged at a convenient rate through a current limiting resistor from a high voltage power unit. The flash tube is connected across the terminals of the condenser, and at the required instant, the discharge is initiated by the application of a high voltage pulse to an internal electrode near the cathode, or to a wire coiled round the outside of the tube. As will be shown in a later section, from the photographic point of view, the important characteristics of the resulting light flash are: the rate of rise of the light intensity to its maximum value, the peak intensity, and the width of the intensity-time curve at an intensity value equal to half that of the peak. These constants are determined by the capacity of the condenser used, by the potential to which it is charged, by the resistance and inductance of the whole circuit, and by the gas used and the pressure at which the tube is filled.

Discharge tubes with very diverse ratings and characteristics have been made by commercial firms and used successfully for different applications. Condensers with capacities between 0.05 microfarads and 4,000 microfarads, the smallest charged to potentials of 15,000 volts, and the largest to potentials of about 2,000 volts, have been discharged. Within these limits, the half width of the intensity-time curve varies from a fraction of a microsecond to several milliseconds. Tubes have also been used for producing sequences of flashes and for continuous operation at flashing rates up to several thousand per second. The maximum mean rate of conversion of energy is about 5 kilowatts, which limits the energy per flash to 5 joules for rates of 1,000 per second.

The heavy duty single flash tubes have been described in a number of previous papers.[4, 5] In this paper the main emphasis will be on medium

rating tubes, which are capable of producing flashes of a few microseconds duration when used with suitable condensers. These have not previously been discussed in detail. A number of observations, based on experimental work, will, however, be made which have a bearing on the design of heavy duty tubes and tubes for multiple flash operation.

The main variables in discharge tube design are: the nature and pressure of the gas filling, the dimensions and shape of the envelope of the tube, the electrode material, electrode shape, inter-electrode spacings, and activation treatment. The tubes are usually filled with argon, krypton, xenon, or mixtures of these inert gases. In each case, the spark spectrum of the inert gas, accompanied by a strong continuum, is excited during the discharge. The spectral distribution of the light from an argon flash is satisfactory for scientific work, the intensity maximum lying in the blue-violet, the region of maximum sensitivity of blue sensitive photographic plates. For colour photography and general non-scientific applications, krypton and xenon filled tubes will give better rendering of tones, because of the more uniform distribution of the continuum and of the lines of the spark spectrum over the visible wavelengths. Low-pressure tubes filled with xenon give a greater integrated light output than identical tubes filled at the same pressure with argon and used in the same circuit. Comparative results for tubes filled with krypton, xenon, and argon at atmospheric pressure do not appear to be available. Hydrogen, added to the inert gas, increases the breakdown potential at a given pressure and prevents the erratic spontaneous breakdown which is often a troublesome feature in high-pressure tubes with wide envelopes. Electro-negative impurities should be avoided in the gas filling; tubes containing traces of oxygen are liable to show very erratic triggering behaviour.

The war-time experimental work in the Ministry of Supply was directed towards the development of short duration flash tubes for photographing shells by reflected light, and it was found at an early stage that the pressure of the gas filling was a most important design factor. With a given electrical circuit, the duration of the flash decreased and the peak intensity increased as the pressure of the inert gas was increased from about 300 mm. Hg. to above atmospheric pressure. At atmospheric pressure, difficulty was experienced in initiating the discharge. For inter-electrode distances, with which initiation was possible at a given working potential, the tubes were usually unstable and liable to become spontaneously conducting without the application of a triggering pulse. With slightly greater inter-electrode distances, they were stable, but it was not possible to trigger the tube at an accurately determined instant, long and variable delays between 10 microseconds and a few milliseconds being encountered. These difficulties did not appear at pressures below 250 mm. Hg. The main problem which had to be solved in producing a high-intensity microsecond flash tube was that of initiating the discharge with a constant delay of not more than a few microseconds, since subjects, for photographing which a microsecond flash tube is essential, usually demand very precise timing of the flash. This leads to consideration of the influence of the tube envelope and of the electrodes.

High-voltage cathode ray oscillograms of the current-time and voltage-time variation during the discharge proved that the shape of the electrodes had no influence on the characteristics of the discharge in high-pressure tubes. As soon as this was established the convenient rod shapes were adopted for the anode and the cathode, and when introduced the internal triggering electrode was in the form of a ring surrounding the cathode. It was found that a pointed triggering electrode tended to make the discharge tube unstable. Experience

showed that to ensure stable operation it was desirable to hydrogen-furnace the electrodes for all tubes before sealing in and to de-gas them fully during the evacuation of the envelope, which should be baked at as high a temperature as possible.

Envelopes with spiral coils of glass or quartz have to be filled at low pressures, otherwise they cannot be triggered on account of the de-ionising influence of the wall. When used with the same electrical circuit, the duration of the flash with a low-pressure coiled tube is much greater than with a straight tube with a smaller inter-electrode spacing, filled to a higher pressure.

The electrical circuit, rather than the gas pressure, determines the duration of the discharge under heavy loading, and for these conditions the tubes are usually made with spiral envelopes and filled with krypton or xenon at low pressures. In tubes with small diameter envelopes of straight or spiral form, the relatively large surface area of the wall favours rapid de-ionisation of the gas after the flash, although by the same mechanism it tends to delay the initiation of the discharge. This property is desirable when flashing at high repetition rates is required, and for these applications low-pressure fillings have to be used because of the high-power dissipation; precise triggering of the burst of flashes is not usually necessary. Regular spacing of the flashes within the burst is, however, essential, as this determines the frame spacing on the film, but no difficulties arise in this respect, because after the first flash there is always considerable residual ionisation. Taking the different factors into consideration, the experimental work on the influence of the shape of the envelope on the duration of the flash showed that for microsecond flashes, initiated with the minimum delay, a straight tube with a diameter wide compared with the diameter of the discharge channel should be used.

Tubes were therefore made with envelopes of 30 mm. diameter glass tubing, with short rods of tungsten or nickel for the anode and cathode, which were about 30 mm. apart along the axis. They were filled to atmospheric pressure with a mixture of 95 per cent. argon and 5 per cent. hydrogen, and initiated by applying a high voltage pulse to an external band near the cathode. Even when the maximum amplitude of the triggering pulse was about 30 kv. there were delays and uncertainties over initiation, and when the discharge did occur, it usually followed the wall from the neighbourhood of the triggering band to the anode, causing crazing and sintering, and often disintegration of the tube. This jagged and diffuse discharge was a most undesirable feature. Further, a triggering pulse of this amplitude can only be produced conveniently by discharging a condenser through the primary of an induction coil, and because of the high self-capacity of the secondary winding there is usually a delay of between 15 and 30 microseconds in the attainment of the peak potential.

Many electronic circuits are available for producing a triggering pulse with a maximum amplitude of 5,000 to 6,000 volts, reached within less than a microsecond of the application of an input signal, and attempts were made to make discharge tubes which could be triggered by such pulses. As a first step, a third electrode was introduced in the form of a ring surrounding the cathode. When the anode and cathode consisted of nickel or tungsten rods and the pressure was greater than 400 mm., triggering was uncertain, even when a small spark passed from the third electrode to the cathode. These three electrode tubes, and two electrode tubes fitted with external triggering bands behaved quite satisfactorily at pressures below 300 mm. Hg., but the duration of the flashes, even with small condensers, was too great to allow clear projectile photographs to be taken. However, these triggering difficulties disappeared

entirely when the electrodes were saturated with an alkali metal, and copper treated with potassium proved to be the most satisfactory material for high pressure, short duration flash tubes.

A number of qualitative observations of the influence of the variables on the properties of the light flash were made. It was found that, if the gas pressure was fixed and a condenser of the same capacity was used, the working voltage could be varied by varying the inter-electrode spacing, without appreciably affecting the flash duration. The light output was approximately proportional to the amount of energy stored in the condenser, and therefore the shortest duration flashes of a given integrated intensity would be produced by using small capacities charged to high potentials, because the duration increases with the capacity. When the working voltage is kept constant, the interelectrode distance can be increased if the pressure in the tube is reduced. The width of the discharge channel is increased, the rate of rise of the light intensity to its maximum reduced, and the half width of the intensity-time-curve increased. Apart from this, other conditions being constant, the light output increases with the interelectrode distance; and at a fixed working voltage and gas pressure, the largest interelectrode spacing with which reliable breakdown can be obtained should be used. Tubes filled at pressures below 300 mm. Hg. allow far larger amounts of electrical energy to be discharged through them without shattering, but the definition in photographs taken with them is never as good as in those taken with high-pressure tubes.

This section has been written from the rather critical viewpoint of application to ultra-high-speed photography. For most applications, the flash produced by any discharge tube will be of sufficiently short duration to completely arrest

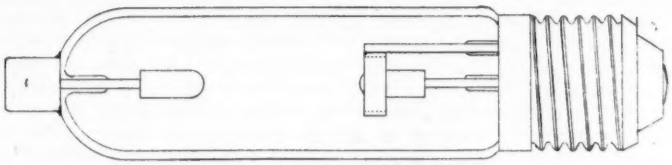

Fig. 1. Line drawing of Arditron Tube.

motion, and low-pressure tubes triggered by the application of a high voltage pulse to an external band are entirely satisfactory. These are usually made with either a straight envelope or a helical envelope, and have been described in papers presented to the Society by Dr. J. N. Aldington(4) and Mr. C. R. Bicknell.(5)

The Manufacture of Microsecond Flash Discharge Tubes

Discharge tubes with potassium-treated copper electrodes were called Arditrons, from the initials of the Armament Research Department. The design is shown in Fig. 1. The envelope is made from boro-silicate glass of 27 to 30-mm. internal diameter and 1.5 to 2-mm. wall thickness. The anode and cathode are copper rods, rounded and polished at one end, and soldered to 1.5-mm. diameter swaged tungsten leads with copper-silver eutectic hard solder, at the other. The triggering electrode is a copper ring, similarly soldered to a tungsten lead. Arditrons for a wide range of working voltages and light outputs can be derived from the basic design by varying the inter-electrode spacing and the gas pressure. Low-pressure Arditrons have many applications, but cannot be used for photographing projectiles in flight.

After the assembly of the tube, the electrodes are cleaned and deeply etched

in a suitable reagent until they show a clear pink crystalline structure. The envelope is then washed thoroughly with distilled water, dried and sealed on to the pumping system and evacuated and baked for about an hour at 450 deg. C. Pure potassium is then distilled into the envelope from a side-arm and is absorbed by the electrodes. When their surfaces are saturated, the tube is allowed to cool, and any excess potassium on the walls distilled out by gentle torching. A mixture of 95 per cent. oxygen-free argon, containing not more than one per cent. of nitrogen, and five per cent. oxygen-free hydrogen, is then admitted to a pressure of about 760 mm. Hg. and the tube is sealed off.

The use of potassium-treated electrodes renders the starting of the tube completely reliable, removing all delays and uncertainties and permitting the use of low triggering potentials. For a given pressure and working voltage, the inter-electrode distance for which breakdown can be obtained is increased, and because of this, the light output is greater than in a shorter tube with inert electrodes. The electrode material is not sputtered on to the wall during operation, and the discharge is confined to a very narrow axial channel, so that there is no sintering and crazing of the walls. Larger amounts of electrical energy can be discharged without damage to either the tube or the electrodes, than in tubes of similar design with inert electrodes, and the life of the tube is considerably greater. Although electrodes of this type may with advantage be used for all medium-energy discharge tubes where reliable initiation is of primary importance, they are not essential for low-pressure tubes in which plain tungsten, nickel or iron electrodes are commonly employed; these materials do, however, sputter on to the wall during operation. Potassium treated copper electrodes are not suitable for heavy-duty tubes, in which the electrodes become heated during the discharge, or for multi-flash tubes, which are intended for continuous operation with a power input of about 5 kw. When the electrodes become heated, the potassium tends to distil on to the walls and into the discharge channel, causing a continuous arc discharge. As tubes for these applications are usually filled at low pressures, activation of the electrodes is not essential, but barium-copper and barium-nickel alloys, made by melting the constituents together in vacuum in a high-frequency induction furnace, can be used either as massive electrodes or as inserts into inert electrodes.

Failures with the high-repetition-rate tubes are usually due to local overheating of the electrodes. The onset of this condition is retarded by the use of a metal with a high thermal conductivity, by increasing the proportion of hydrogen in the gas-filling, and on account of the additional need for effective de-ionisation between flashes, by decreasing the diameter of the tube envelope. Because of the heating of electrodes and of the envelope which takes place, the characteristics of these tubes are not stable during a burst of flashes. The highest loading is possible in tubes with fused quartz envelopes, which may reach red heat during operation.

Electrical Circuits For Use With Gas-Filled Discharge Tubes

A typical circuit for single-flash operation is shown in Fig. 2. There are three component parts; the rectifier unit, which provides the high potential for charging the flash condenser; the condenser, the leads to the discharge tube, and the discharge tube; and the triggering circuit. Experience showed that for most applications involving the use of microsecond flashes for high-speed photography, a satisfactory performance was given by a tube with an inter-electrode distance of 30 mm. filled to atmospheric pressure with the argon-hydrogen mixture, and used with a condenser of two microfarads capacity, charged to a potential between 7.5 and 8 kv. A higher voltage would

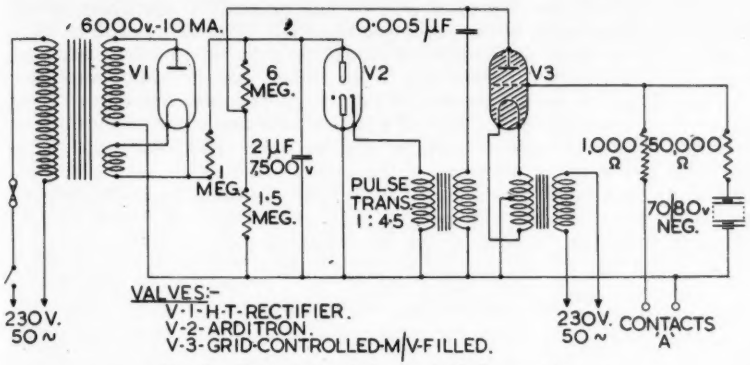

Fig. 2. Typical circuit for single-flash operation.

have been selected if suitable rectifying valves had been available, and if the equipment had not often had to be exposed to unfavourable atmospheric conditions. Two microfarads is the maximum capacity which can be used for shell photography without there being an appreciable loss of detail through blurring.

The transformer in the circuit is rated at 6,000 volts R.M.S., and the flash condenser, which acts as the smoothing condenser for the half-wave rectifier circuit, is charged through a 1 megohm resistance. A 7.5 megohm potentiometer is connected across it. The minimum possible flash duration is determined not by the discharge tube, but by the electrical circuit constants, and for this reason the flash condenser must have a low internal resistance and self-inductance, and the leads which connect the condenser to the discharge tube must enclose a loop of small area. If long leads are necessary, they should be of high-capacity, low-inductance concentric cable. In these circuits, heavy currents flow during the discharge, and the sections of the condenser must be carefully assembled with heavy, well-spaced connecting leads. The life of a standard high-voltage smoothing condenser is limited if it is used for this work. The weight of reliable high-voltage condensers is at present a serious disadvantage, which tends to prevent the wider introduction of flash photography methods. It will undoubtedly be reduced in the future by the use of high dielectric constant materials with improved insulating properties. These remarks apply mainly to circuits used for producing microsecond flashes The same exacting conditions do not have to be fulfilled with the relatively high-capacity condensers which are charged to potentials between 2,000 and 3,000 volts for use with low-pressure tubes in commercially available apparatus. In fact, as will be discussed in the section on photographic methods, the conditions under which such apparatus is often used make it desirable for the flash to be lengthened rather than shortened.

The Trigger Circuit

The triggering pulse is usually produced by a circuit in which a small condenser and the primary of an induction coil or pulse transformer are connected in series with a hot cathode gas-filled triode. The discharge of the condenser is prevented by the application of a negative potential to the grid of the triode. When this is reduced by feeding a positive pulse to the grid, the condenser discharges through the primary of the transformer and the valve, and the triggering potential appears across the transformer secondary.

The type of step-up system used will be determined by the delay which can be tolerated between the event pulse and the flash. The value of 15 to 20 microseconds obtained with an induction coil can be reduced to a few microseconds by the use of a pulse transformer with a low leakage inductance primary and a low capacity secondary wound on a high permeability core. The pulse transformer ratio should not exceed 4.5 to 1 and small gas triodes which can be operated with an anode voltage greater than 1,500 volts are not available. This limits the application of the pulse transformer circuit to discharge tubes which can be initiated by a pulse with a maximum amplitude of less than 6,000 volts. When used with a 0.005 microfarad condenser charged to 1,500 volts from the tapping of the 7.5 megohms potentiometer, and a B.T.19 mercury-filled gas triode, a suitable transformer will deliver a pulse rising from zero to a maximum value of 6 kv. in not more than 0.5 microseconds after the application of the event pulse to the grid. Arditrons are triggered by such pulses without measurable delays when used under specified conditions.

The event pulse may be produced by breaking a contact between the negative grid bias supply and the grid; by making a contact between the grid and the cathode; by feeding a positive pulse from a photocell amplifier circuit to the grid through a condenser or in many other ways.

The Properties of a Standard Arditron Tube

The standard Arditron has an inter-electrode spacing of 30 mm. and is filled to atmospheric pressure with an argon-hydrogen mixture. It is used with a 2 microfarad condenser charged to potentials between 5 and 10 kv., the recommended working voltage being 7.5 kv. The tube is liable to break down spontaneously if the condenser is charged to a potential greater than 11.5 kv. When a positive pulse, with a maximum amplitude of 5 kv. reached in less than 1 microsecond, is applied to the third electrode, breakdown occurs within 16 microseconds at a working potential of 5 kv., in 2 microseconds at a potential of 7.5 kv., and above 8 kv. the delay is too small to be measured. The discharge occurs along a narrow axial channel. With a condenser of 2 microfarads capacity, used in a circuit having 0.8 microhenries total self-inductance, and 0.2 ohms resistance, the maximum discharge current is 7,000 amperes at 1.8 microseconds from zero, and at the current maximum the potential across the tube has fallen to 1,200 volts. The first half-cycle period is 4 microseconds. The peak rate of working of 12 megawatts is reached in the first quarter cycle.

The photographic evidence indicates that the time required for the light output curve to attain its peak value is 0.75 microseconds and that the effective photographic duration of the flash for reflected light photography of matt objects is not greater than 1.5 microseconds. The total integrated light output, measured with an electronic integrating photometer, fitted with a yellow green filter, giving a transmission maximum in the region of maximum sensitivity of the eye, was 33 lumen-seconds. This is a lower limit for the light output, which was shown from spectograms to have a minimum value in this region. The maximum lies in what is photographically the most actinic region of the spectrum, about 4,300 A., and by a photographic photometric method the estimated light output from the tube is 180 lumen-seconds. The accurate measurement of this quantity is very difficult. The measurements showed that the light output was extremely constant over successive flashes, and that the emission was uniform along the whole length of the discharge channel.

Tubes have been subjected to prolonged life testing under standard

operating conditions. No tube of this type failed within 5,000 flashes, and tests were not continued beyond this point. One tube, tested in an automatic circuit with a 0.5 microfarad condenser charged to 10,200 volts, was flashed at three flashes per minute for 10,000 flashes. The breakdown characteristics were measured before and after the test and were found to be unchanged. No flashes came into contact with the wall, and there was only barely perceptible sputtering of copper on to the wall near the anode.

The Problems Associated with Discharge Tube Operation at High Repetition Rates

The details of power circuits for the continuous operation of discharge tubes at high repetition rates will not be considered. There are at present many unsolved problems in this field, mainly connected with the behaviour of the discharge tubes themselves and some of these difficulties will be discussed and possible solutions indicated.

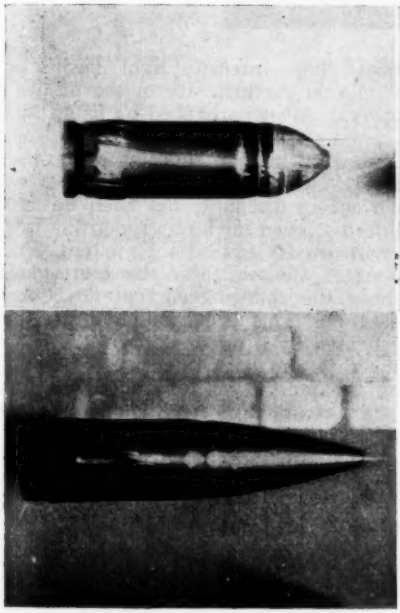

Fig. 3 *(left)*. A 2-pounder shell in flight.

Fig. 4 *(right)*. A 2-pounder shell after passing through a sheet of armour-plate.

Fig. 5 *(bottom)*. A 6-pounder shell in flight.

(These photographs were taken with Arditron units by Mr. J. T. Harris, of the Armament Research Dept., on blue sensitive medium speed photographic plates. The two-microfarad condenser was charged to 7,500 volts. The triggering pulse was produced by a gas-triode pulse transformer circuit, the event pulse being obtained when the impact of the shock wave of the shell on a steel diaphragm opened a contact.

The electrical circuits will present no serious difficulties when satisfactory discharge tubes are available for use with them. In most multiple flash circuits, the condenser is charged from the rectifier unit, either through a series resistance or inductance. At high repetition rates, a large charging current must flow during the dark period between flashes, this current increasing as the condenser capacity is increased to produce more intense flashes. There will be a high rate of change in the potential across the condenser and therefore in the potential across the flash tube, and any inert gas-filled discharge tube tends to break down under these conditions. This limits

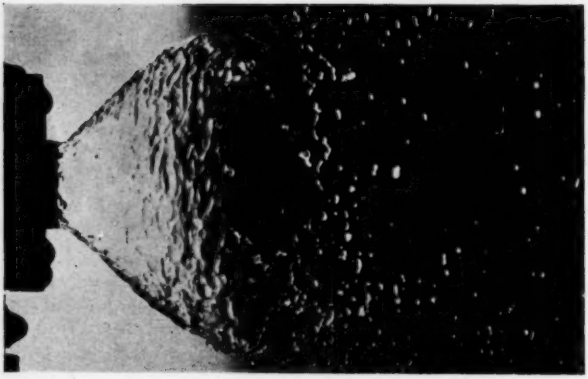

Fig. 6. This photograph shows the disintegration of a thin conical sheet of water, produced by allowing a stream of water to flow internally over a hollow conical surface rotating at high speed. It was taken by Mr. Aspden, of the Royal Aircraft Establishment, Farnborough.

the repetition rate in series circuits when high intensity light flashes are the primary requirement, and conversely limits the intensity of the flashes at high repetition rates. The tendency to break down is reduced by using tubes with narrow envelopes, inert electrodes, and a considerable amount of hydrogen in the filling. This difficulty is experienced during the charging cycle; there are also difficulties during the discharge cycle. Inert gas-filled tubes will conduct down to very low currents when once a discharge has been initiated, and when high intensity flashes are required at even moderate repetition rates, the charging current which must flow will usually exceed the current which can maintain the tube in a conducting state. Consequently the inert gas is not de-ionised and what should have been the charging current flows as a continuous low current arc through the tube. This is particularly likely to happen when the electrodes have been heated by a burst of flashes, and imposes a severe limitation on the repetition rate and flash intensity. The difficulties are partially overcome by using the inert gas-filled tube as a light source, in series with a hydrogen-filled or a mercury pool electrode control tube both of which have more rapid de-ionisation characteristics. Even with these more complicated circuits, the mean power dissipated cannot exceed about 5 kw., and at flashing rates of 1,000 per sec., the illumination is sufficient to permit only rather limited areas to be photographed, or to allow the subject to be recorded as a silhouette against a white background.(7)

The problems associated with these systems have not yet been solved with purely electronic circuits. If the condenser is charged independently of the discharge tube from a power supply through a series inductance or resistance, and connected with it by a mechanically closed spark gap of small spacing, only during the actual discharge, many of the limitations are removed. With a rotary gap regularly spaced flashes at rates of 1,000 per sec. can be produced until the tube breaks down through overheating. At present, for the production of high intensity flashes it seems necessary to mechanically separate the discharge tube from the condenser during the dark interval, to allow the de-ionisation of the tube and the charging of the condenser. Even when this has been done, the definition obtained is poor compared with that of photographs taken on stationary plates or films. The tubes have to be filled at low pressures and the inductance of a circuit including a control tube or a mechanically closed gap is considerably greater than that of a well designed single flash circuit. This reduces the rate of rise of the light intensity curve

and also the peak intensity and gives a rather wide half width. For a repetition rate of 1,500 frames per sec., the film must be moved at a high speed, and under these conditions the duration of the flashes produced by available equipment is too great, even stationary objects in the field giving rather blurred images. Many valuable laboratory records have been obtained, but before this method can really establish itself, the flash intensity must be increased to allow greater areas to be illuminated for photography by reflected light and the flash duration must be reduced to improve the definition of the individual frames.

It appears that an early solution of these problems cannot be expected, and that if cinema records taken at rates of about 1,000 frames per sec. are essential for an investigation, a camera of the Vinten H.S. 3,000 type will have to be used, unless only very limited areas are involved.

Multiflash systems could be developed with less difficulty for operation at flashing rates below 50 per sec., and might find application in the future for studio work and cinema projection. At these low flashing rates the main problems to be solved are connected with the excessive heating of the envelope

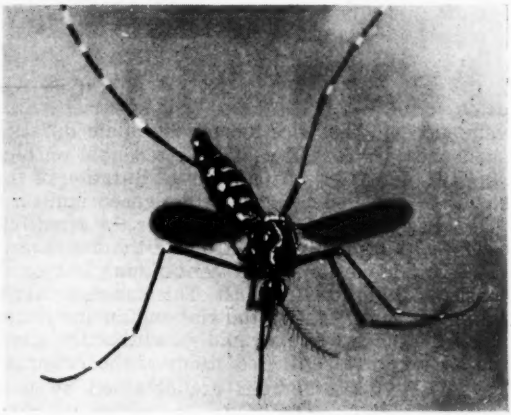

Fig. 7. A mosquito in flight, taken on a blue sensitive plate at 15 X magnification by Mr. Walton and collaborators at the Chemical Defence Research Establishment, Porton. The camera was focussed on the point of intersection of two narrow beams of red light meeting at right angles in the centre of a container, and then passing into two red sensitive photoelectric cells. The mosquitoes flew freely round the container and an electronic circuit was used to trigger the Arditron, of which the beam was focussed on the intersection by a spherical mirror, when the mosquito *simultaneously* interrupted both beams.

and the electrodes at heavy loadings, and with the resulting change in the operating characteristics of the tubes.

After this outline of the problems associated with multiple flash photography, the remainder of the paper is devoted to single flash work.

Photographic Technique in High Speed Photography by Reflected Light

The light flash, which is produced by a discharge tube—even after everything which at present seems possible in the way of circuit design and tube design has been done—does not have ideal characteristics, and if the best results are to be obtained careful attention has to be paid to photographic technique. With an argon discharge at high pressures, the light output-time curve has a sharply peaked maximum, due to a high rate of rise to the peak and an immediate rapid fall beyond it, which is very favourable for high speed photographic work. The light intensity, however, requires 50 microseconds to die away to zero from the maximum, although this is irrelevant for practically all single flash applications. This sharp rise to the peak which occurs within 0.75 microseconds and the narrow peak, determine a maximum photographic duration of

1.5 microseconds which is considerably less than would be expected from the circuit constants. The high rate of rise of the light output in an argon discharge is shown in oscillograms in a paper by Craggs and Meek.[8]

The effective photographic duration of the discharge can be conveniently determined in a ballistic laboratory by taking shadow photographs of a bullet in flight. A pin-hole of about 1 mm. diameter in a card is fixed to the wall of the tube, which is set up about 6 ft. from the line of flight of a flat-based 0.303-in. Mk. VII bullet. A photographic plate is placed about 1 in. beyond the line of flight and the discharge is triggered when the bullet is over the centre of the plate. The time scale is determined by the known velocity of the bullet. In the records, the bullet is sharply outlined by the rapid initial rise of the light intensity from zero to its peak value. The background gives a measure of the total integrated intensity of the light flash, and in the region in front of the bullet, the illumination during the after-glow period is subtracted from the background intensity. Similarly, in front of the sharply defined base of the bullet, previously unexposed film is exposed to the afterglow, and the variation of intensity with distance gives the time interval required for the intensity of the afterglow to fall below the threshold exposure for the photographic plate.

Records obtained in this way with a range of capacities and photographic plates gave valuable information on the photographic characteristics of the discharge tubes. The durations determined with slow blue sensitive film were very close to the effective photographic durations estimated from bullet and shell photographs taken by reflected light on blue sensitive emulsions of speed about H. and D.800. The apparent duration of the discharge determined by the shadow method depended on the speed and on the spectral sensitivity of the plates used. It increased rapidly as the sensitivity of the plates was extended towards the red. The spectrum of the discharge in the red shows mainly lines of Argon I overlain by a continuum, whereas the far blue violet spectrum consists of lines of Argon II. This suggests that the blue-violet spark spectrum is emitted during the initial rise and during the peak period of the light output, but then dies away very rapidly and that the afterglow is mainly associated with the longer wavelength radiations of the Argon I spectrum.

The best photographs are obtained by using the slowest possible blue sensitive plates. The limitations which the duration of the light flash would impose can be minimised by paying careful attention to the exposure and to the intensity of the source viewed from the position of the object being photographed. The negative should be no more than adequately exposed to give a good enlargement on a medium contrasty-paper. Over-exposure accentuates the effect of the duration of the flash.

Exposure can be controlled by varying the lens aperture or adjusting the distance between the light source and the object. No tails are ever observed in photographs of matt objects. When shiny objects which are liable to give direct reflections have to be photographed, the high-lights should be painted with matt white, grey or black paint, or if this is not possible a large diffusing screen should be placed in front of the light source. If there is a direct reflection of the light source into the lens, the image of the high-light will show a tail, representing after-glow emission for a period of about 30 microseconds. Although this does not effect the scientific value of the records it detracts from their aesthetic value. Apart from this, standard photographic illumination practice should be applied for the best results; reflectors can profitably be used to give more uniform illumination and to reduce shadow contrasts, and grey backgrounds are usually most effective. These remarks apply mainly to

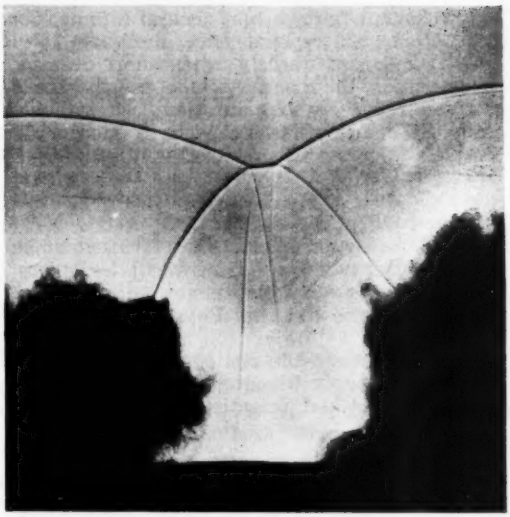

Fig. 8. This photograph was taken on an extremely slow blue-violet sensitive photo-mechanical emulsion by Mr. I. S. Nixon and the author in the Armament Research Dept. It shows the intersection of the two approximately spherical shock waves which spread from the ends of a rod of detonated high explosive, confined by a hollow steel cylinder with a horizontal axis.

exacting cases of shell photography, because the effects of the duration of the discharge can be detected in very few other applications.

Discharge tubes were also used for producing shadow photographs of objects moving with velocities greater than the velocity of sound to show the shock waves and related disturbances. For this purpose the tube was set up with its cathode near the centre of curvature of a concave spherical mirror. A pinhole, 1.5 mm. in diameter in a card was stuck on to the wall of the tube, which was used with a 0.5 microfarad condenser charged to 7.5 kv. The light source was placed 6 to 12 ft. from the region which was to be photographed and sheets of blue-violet sensitive, low speed and high-contrast photo-mechanical film were placed in a suitable holder about a foot beyond it. High definition pictures with clearly defined shock waves were obtained.

There is a serious limitation to the use of this method of flash photography in daylight or in relatively bright general illumination. The attempt is usually made to synchronise the flash from the discharge tube with the instant of maximum opening of a mechanical shutter set to give an exposure of about 1/250th of a sec. In these conditions, depending on the instant of the flash in the exposure interval, the film will be pre-exposed for a certain time to the background of the event, will receive an image due to the high intensity short duration flash, and will then again be exposed to the background at the lower level of the general illumination. The pre-exposure may sensitise the film to the flash exposure, but the subsequent exposure, following the high intensity flash, leads to a serious loss of contrast in the developed image and even partial reversal. In photography this is referred to as the Clayden effect. The best results can only be obtained by working in the brightest possible safe-light illumination for the emulsion being used and the blue sensitive emulsions have therefore a considerable advantage over ortho- and panchromatic emulsions.

Some emulsions are particularly susceptible to this type of reversal. This effect can be very serious when discharge tube flash illumination is used

to supplement fairly bright general illumination as in many press photography applications; the reversal effect decreases as the duration of the discharge increases and consequently when short duration exposures are not a primary consideration, the discharge tube and the associated circuit should be designed to give a relatively long duration flash without a sharply peaked intensity-time curve. The use of large capacity condensers with discharge tubes with helical channels filled at low pressures will minimise the effect.

Acknowledgments

The collaboration of Mr. J. T. Harris, Mr. E. W. Walker, Mr. I. S. Nixon, Mr. R. G. Adamson, members and former members of the staff of the Armament Research Department, during the later stages of Arditron development and application is gratefully acknowledged. Mr. J. S. Preston and Mr. W. G. Standring of the National Physical Laboratory also gave valuable assistance and advice.

This paper and the photographs, which were taken with Arditron units in Ministry of Supply Research Establishments, are published with the kind permission of the Chief Scientist, Ministry of Supply.

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The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

Report of the Council*

(January 1 to December 31, 1948)

The year 1948 has been memorable in the history of the Society, on account of events which the Council can report with gratification, but also of sad bereavements in which the Society has lost two of its most distinguished members. Two notable new activities of the Society during the year were the very successful Summer Meeting at Harrogate and the inauguration of the Register of Lighting Engineers. There is increasing evidence of the respect in which the Society is held, not only in Great Britain but abroad, which is a source of satisfaction.

Officers, Council and Standing Committees for Session 1948-49

In accordance with the procedure laid down in the Articles and By-laws of the Society, nominations made by the Council to fill vacancies for the Session 1948-49 were circulated to Corporate Members, who were given an opportunity to make additional nominations. No new nominations were received, and the proposals of the Council accordingly became effective, the following being elected:—

President: Mr. J. M. Waldram.
Vice-Presidents: Dr. E. C. Walton, Mr. E. W. Murray, and Dr. J. N. Aldington.
Hon. Treasurer: Mr. J. G. Holmes.
Hon. Secretary: Mr. H. C. Weston.
Hon. Editor of Transactions: Mr. W. R. Stevens.

The following were elected as members of Council in place of those retiring:—

Mr. A. D. S. Atkinson, Mr. H. S. Barlow, Mr. G. H. Giles, Dr. H. F. Gillbe, Mr. E. C. Lennox, Mr. L. C. Rettig, Mr. W. T. F. Souter, Mr. S. G. Turner.

The following were appointed to represent their respective Centres on the Council:—

Bath and Bristol: Mr. L. Burdes; *Birmingham*: Mr. W. J. P. Watson; *Cardiff*: Mr. J. S. Childs; *Edinburgh*: Mr. S. G. Batt; *Glasgow*: Mr. D. Ross; *Gloucester and Cheltenham*: Mr. J. Davoile; *Leeds*: Mr. J. D. Green; *Leicester*: Mr. F. Jamieson; *Liverpool*: Mr. O. C. Waygood; *Manchester*: Mr. H. Atherton; *Newcastle*: Mr. H. James; *Nottingham*: Mr. E. G. Phillips; *Sheffield*: Mr. B. Bingham.

The attendance of ordinary members of Council and representatives of Centres at Council meetings during the year is shown in the accompanying table.

The Standing Committees as from October 1, 1948, were constituted as follows:—

GENERAL PURPOSES COMMITTEE: J. M. Waldram (*President*); J. G. Holmes (*Hon. Treasurer*); H. C. Weston (*Hon. Secretary*); J. W. T. Walsh (*Past-President*); E. C. Walton, E. W. Murray (*Vice-Presidents*); C. J. Allderidge (*Birmingham Centre*); H. Atherton (*Manchester Centre*).

AREAS JOINT COMMITTEE: One representative from each Centre. Council's Representatives: C. R. Bicknell, J. H. Nelson, W. R. Stevens.

PAPERS COMMITTEE: A. D. S. Atkinson, C. R. Bicknell, T. S. Jones, A. G. Penny, F. C. Smith, J. S. Smyth, P. C. Sugg, O. C. Waygood *Co-opted*, J. S. Preston, J. N. Hull.

EDUCATION COMMITTEE: R. O. Ackerley, H. S. Barlow, A. Cunnington, P. Good, C. E. Greenslade, W. J. Jones, S. D. Lay, J. T. MacGregor-Morris, F. C. Smith, W. R. Stevens, J. W. T. Walsh. *Co-opted*, S. S. Beggs.

CODE COMMITTEE: R. O. Ackerley, C. R. Bicknell, J. H. Nelson, F. C. Smith,

* To be presented at the Annual General Meeting, to take place at The Royal Society of Arts, John Adam-street, London, W.C.2, at 6 p.m. on Tuesday, May 10, 1949.

J. S. Smyth, W. T. Souter, J. F. Stanley, J. W. T. Walsh, H. C. Weston. *Co-opted*, E. B. Sawyer.

DEVELOPMENT COMMITTEE: R. O. Ackerley, A. D. S. Atkinson, T. S. Jones, S. D. Lay, A. G. Penny, L. C. Rettig, S. G. Turner. *Co-opted*, H. H. Ballin, J. T. MacGregor-Morris, G. A. Wedge, R. Pulman, L. Stokes-Roberts, C. A. Hoskins, B. Besemer.

The Council record their thanks to members who have given their time to the increasing committee work of the Society.

Attendance at Council Meetings

(a) NOMINATED MEMBERS OF COUNCIL

Name	Possible Attend.	Actual Attend.
C. J. Allderidge	8	4
C. R. Bicknell	8	7
H. Bright	8	1
L. J. Davies	8	0
C. E. Greenslade	8	6
T. S. Jones	8	3
S. D. Lay	8	8
H. S. Lingard	8	0
J. H. Nelson	8	1
A. J. P. Pashler	8	3
A. G. Penny	8	7
J. S. Smyth	8	5
J. F. Stanley	8	5
W. R. Stevens	8	7
P. Crawford Sugg	8	2
F. Walker	8	2
W. M. Hampton	5	0
A. G. Higgins	5	4
E. B. Sawyer	5	5
W. S. Stiles	5	1
W. D. Wright	5	1
A. D. S. Atkinson	3	2
H. S. Barlow	3	1
G. H. Giles	3	2
H. F. Gillbe	3	3
E. C. Lennox	3	1
L. C. Rettig	3	2
W. T. F. Souter	3	3
S. G. Turner	3	3

(b) REPRESENTATIVES OF CENTRES

Centre	Possible Attend.	Actual Attend.
Bath and Bristol	8	4
Birmingham	8	8
Cardiff	8	6
Edinburgh	8	0
Glasgow	8	1
Gloucester and Cheltenham	8	0
Leeds	8	2
Leicester	8	7
Liverpool	8	1
Manchester	8	6
Newcastle	8	1
Nottingham	8	2
Sheffield	8	5

Meetings In London

Seven Sessional Meetings were held in London during the year; the Annual General Meeting formed part of the proceedings at the Summer Meeting, an account of which appears elsewhere in this report. The subjects dealt with at these Sessional Meetings were: "The Application of Modern Flash Discharge Tubes," by C. R. Bicknell; "The Lighting of Architecture," by G. Grenfell Baines; "High Voltage Fluorescent Tubes," by H. G. Jenkins and J. N. Bowtell; "Photographic Illumination in Motion Picture Studios," by F. S. Hawkins, F. V. Hauser, and W. R. Stevens; the Presidential Address, by J. M. Waldram; "High Speed Photography," by J. W. Mitchell, and "The Gas Arc—A New Light Source," by J. N. Aldington.

In addition to the Sessional Meetings, Informal Meetings and Visits were included in the London programme. The Informal Meetings included a discussion on the motion, "That good Artificial Lighting is an Adequate Substitute for Natural Lighting," and a report and discussion on the Paris meeting of the International Commission on Illumination. Both of these meetings were popular, and it is apparent that such meetings are welcomed by members.

Visits were made to the Plastics Division of the Imperial Chemical Industries at Welwyn Garden City; visits to two film studios in the vicinity of London; a visit to Chislet Colliery to see the experimental installation of fluorescent lighting in the roadways and at the coal face; a visit to the Research Laboratories of the British Thomson-Houston Company at Rugby and a visit to Southampton Docks.

Centre and Group Activities

The various Centres and Groups again arranged interesting programmes, including a number of successful joint meetings with other bodies. Several papers which had previously been given in London were repeated in the provinces, but, in addition, the various Centres and Groups were active in sponsoring papers, some of which were given by their own members. Several papers originating in the provinces were brought to the notice of the Papers Committee in London, and were included in the programme of London meetings. The President during the latter part of the 1947-48 Session, Dr. J. W. T. Walsh, visited the Centres at Bath and Bristol, Birmingham, Cardiff, Edinburgh, Glasgow, Leeds, Manchester, and Newcastle, and Mr. J. M. Waldram, President for the Session 1948-49, visited Cardiff, Manchester, Leicester, and Nottingham after taking office and before the end of 1948. On several occasions the President was accompanied by the Secretary, who took the opportunity of meeting local members and committees.

Summer Meeting

The year under review saw a new venture on the part of the Society in the first Summer Meeting, which was held at Harrogate from June 16 to 18. The suggestion that Summer Meetings be held for the provinces from time to time was made before 1939, but the outbreak of the war prevented any such activities. With the return of peace, however, the suggestion was revived and the Council accepted the invitation of the North Midland Area to hold the Summer Meeting at Harrogate.

The local arrangements in connection with the meeting were made by the North Midland Area, comprising the Leeds and Sheffield Centres, which appointed representatives on the Summer Meeting Committee meeting in London. The choice of Harrogate proved to be most fortunate, for it was within easy reach of the large number of I.E.S. members in the North of England; the local authorities were most helpful, making Harrogate an ideal place for such a conference.

The papers selected by the Papers Committee for presentation at this meeting were "Acrylic Plastics in Lighting," by W. E. Harper and H. P. Walker, "Decorative Lighting," by L. H. Hubble; "Department Store Lighting—Factors Influencing the Design," by A. W. Jervis; and "New Lamp Developments," by N. L. Harris. In addition the programme included an informal lecture on "Television," by L. C. Jesty.

It had been agreed that the Annual General Meeting at the end of the 1947-48 Session should form part of the Summer Meeting, and the Society was very fortunate in securing Dr. Ward Harrison, of the U.S.A., to give an address following this meeting on "Some Frontiers of the Lighting Art." The Summer Meeting programme also included several social events, among which was the Annual Dinner, at which the principal guests were Dr. Ward Harrison and M. Henri Maisonneuve, Past President of the Association Française des Eclairagistes.

This was the first meeting of its kind which has been attempted by the Society, and it was, by general consent, most successful. Some 300 members registered as delegates, and even greater numbers attended the various technical meetings. The Council place on record their appreciation of the work done by members in the North Midland Area and others, to ensure the success of this meeting.

Publications

Ten issues of the Transactions were published during the year; the total number of pages was slightly higher than in the immediately preceding years.

In addition to papers presented at Sessional Meetings in London, the Transactions included the papers presented at the Summer Meeting and the address by Dr. Ward Harrison.

Besides these normal issues of the Transactions a special publication was issued entitled "Symposium on Searchlights." This contained the five papers presented at the Sessional Meeting on April 15, 1947, the discussion on these papers, and a further written contribution. As mentioned in the Report of 1947, in view of the length and value of these papers it was decided to make a separate publication of them rather than include them in the normal Transactions. As the papers were specialised, this book was not distributed to members but was placed on sale. The book received excellent reviews in the scientific Press of this country and abroad, and it is felt that it has added much to the prestige of the Society.

By the end of the year the I.E.S. Code for the Lighting of Building Interiors was out of print, and the Council decided that some revision should be made before reprinting. This work is now in hand by the Code Committee and it is hoped that a new edition of the Code will be available early in the current year.

Leon Gaster Memorial Premium

This year the Leon Gaster Memorial Premium, offered for the best paper contributed and published during the session, was awarded by the Council to Mr. H. G. Jenkins and Mr. J. N. Bowtell for their paper entitled "High Voltage Fluorescent Tubes," which was read on March 9. In view of both the large number and the high standard of papers eligible for the award this year, of which the Searchlight Symposium formed an unusual group, the Council made a second award to Dr. H. K. Cameron, Dr. E. H. Rayner, Mr. E. R. Thomas, and Mr. G. T. Winch for their paper entitled "Photometry of Searchlights."

No applications for the Silver Jubilee Commemoration Award were received.

Membership

The additions to membership recorded during the year under review are as follows:—

Corporate Members	267
Associates and Country Members	9
Students	10
Sustaining Members	22

In spite of the number of new Sustaining Members, the total number has decreased. This is due to the fact that, with the nationalisation of the electrical supply industry, a large number of undertakings who were Sustaining Members are no longer able to continue as individual members and have been replaced by the various Area Boards.

It is with great regret that the Council has to record the death of two distinguished members of the Society during the year under review. In July Sir Clifford Paterson, one of the original members of the Society and a Past President, passed away; and in the following month Mr. J. S. Dow, who with Mr. Leon Gaster founded the Society in 1909, died after a very brief illness. The loss of Mr. Dow, who was Assistant Hon. Secretary from 1909-28 and Hon. Secretary from 1928 until 1946, when he became President, is a great blow to the Society. The Society had relied very heavily on Mr. Dow's guidance during the last 39 years, and he was present at every Council meeting during this period. A memorial service to Mr. Dow, arranged by the Society, was held at the King's Chapel of the Savoy on Tuesday, October 19, 1948.

The election of 13 members to Fellowship was announced in the Transactions of the Society during 1948, the number of Fellows now being 159.

TOTAL MEMBERSHIP (December 31, 1948)

Centres :—	Fellows	Corporate Members	Country Members	Associates	Students	Total	Sustaining Members
Bath & Bristol ...	3	64	2	10	—	79	5
Birmingham ...	15	189	—	4	8	216	21
Cardiff	3	83	—	1	3	90	2
Edinburgh	4	48	1	1	—	54	3
Glasgow	6	74	2	2	1	85	2
Gloucester & Cheltenham ...	—	41	—	—	—	41	—
Leeds	6	90	—	2	5	103	3
Leicester	1	50	—	2	—	53	1
Liverpool	1	97	—	—	—	98	8
Manchester... ...	3	133	2	1	1	140	7
Newcastle	3	84	—	2	1	90	4
Nottingham ...	6	60	—	3	3	72	1
Sheffield	4	71	—	1	2	78	2
Groups :—							
Bradford	1	31	—	1	1	34	—
Exeter	1	31	—	—	—	32	2
Huddersfield ...	1	34	—	1	1	37	—
Stoke-on-Trent ...	—	27	—	—	—	27	1
Sussex	3	25	2	—	—	30	1
Tees-side	1	30	—	—	—	31	—
TOTAL ...	60	1,262	9	31	26	1,388	63
Foreign	10	52	38	2	—	102	2
Eire	2	10	9	—	—	21	1
London ...	85	535	4	11	14	649	41
TOTAL ...	159	1,859	60	44	40	2,162	107

Register of Lighting Engineers

As intimated in the report of the Council for 1947, the scheme for operating the Register of Lighting Engineers was announced early in the year, and applications from members of the Society to be admitted to the Register were invited from February 1. The Council set up a Registration Board to examine applications and to recommend applicants to the Council.

The initial stages of administering this scheme naturally take time, for the Board have been anxious to give the most careful consideration to every application. At the end of the year some 55 applications had been considered and the names of 39 members had been included on the Register.

Education

During the educational year ended May, 1948, courses for the Intermediate Examination of the City and Guilds of London Institute in Illuminating Engineering were held at the Northampton and Borough Polytechnics in London, the Central Technical College in Birmingham, Cardiff Technical College, the Stowe College School of Engineering, Glasgow, the Leeds College of Technology and the Manchester College of Technology. The only course for the Final Grade Examination was at the Borough Polytechnic in London. For the educational year beginning in September, 1948, courses for the Intermediate examination were arranged at the Northampton Polytechnic and the Borough

INCOME AND EXPENDITURE ACCOUNT

1947 £	Dr. EXPENDITURE.	£ s. d.	£ s. d.
	To Administration Expenses:—		
1,690	Salaries and State Insurance	1,803 11 2	
240	Rent	249 4 9	
36	Lighting and Heating	41 8 9	
39	Telephone	53 14 8	
331	Printing and Stationery	273 5 8	
127	Duplicating	102 19 1	
181	Postage	193 2 3	
75	Travelling Expenses	142 0 4	
377	Sundry Office Expenses	261 14 0	
	,, Sessional and other Meetings in London:—		3,121 0 8
18	Hire of Halls	24 15 6	
43	Reporting and Lantern Operating	28 7 0	
76	Refreshments and Entertaining Expenses	115 6 6	
			168 9 0
970	,, Expenditure of Centres and Groups		1,097 19 5
21	,, Audit Fee		28 7 0
			4,415 16 1
638	,, Cost of Printing Transactions, Reprints, Blocks, etc. ...		1,172 7 3
89	,, Cost of Printing Symposium on Searchlights		370 19 0
—	,, Equipment for School Lectures		92 4 6
—	,, Expenditure on Summer Meetings (including 1948 dinner) less Sale of Tickets		206 3 0
489	,, Cost of 1946 Convention Proceedings less Sale of Copies		— — —
77	,, Expenditure on 1947 Dinner, less Sale of Tickets ...		— — —
	,, Illuminating Engineering Publishing Co., Ltd.— Allocation and Share of Subscriptions	915 12 0	
403	*Less* Contribution towards administration expenses	500 0 0	
			415 12 0
48	,, Contributions to Kindred Societies		47 15 0
132	,, Premium on Deferred Annuities		132 6 4
			6,853 3 2
309	,, Excess of Income over Expenditure		176 18 11
£6,409			£7,030 2 1

BALANCE SHEET,

1947 £	CAPITAL AND LIABILITIES	£ s. d.	£ s. d.
	Capital Account:—		
	Balance at 31st December, 1947	5,220 16 6	
	Add Excess of Income over Expenditure for the year	176 18 11	
5,221			5,397 15 5
1,000	Reserve for Future Office and Administration Expenses ...		1,000 0 0
—	Trotter Memorial Fund		5 15 6
553	Sundry Creditors		747 19 3
£6,774			£7,151 10 2

FOR THE YEAR ENDED 31st DECEMBER, 1948

1947 £	INCOME.	*Cr.* £ s. d.
5,814	By Subscriptions	6,113 2 0
20	,, Subscriptions Outstanding (Estimated)	20 0 0
426	,, Sales of publications...	704 4 3
—	,, Registration Fees	28 7 0
144	,, Interest on Investments	161 18 10
5	,, Premium on Conversion of Defence Bonds	2 10 0
£6,409		£7,030 2 1

31st DECEMBER, 1948

1947 £	ASSETS.	£ s. d.	£ s. d.
	Investments at Cost :—		
	£1,500 3½% Registered War Stock	1,559 15 0	
	£250 3% Defence Bonds	250 0 0	
	£2,250 2½% Defence Bonds	2,250 0 0	
	£750 2½% National War Bonds	750 0 0	
	£1,000 3% Savings Bonds	1,000 0 0	
5,810	£500 3% British Transport Guaranteed Stock... ...	488 4 6	
	(Market Value 31/12/48 £6,346)		6,297 19 6
843	Balance at Bankers and Cash in Hand		742 14 8
121	Sundry Debtors		110 16 0
£6,774			£7,151 10 2

LEON GASTER MEMORIAL FUND, RECEIPTS & PAYMENTS

	£	s.	d.
To Balance, 1st January, 1948	255	19	4
,, War Stock Interest	8	1	0
	£264	0	4

LIBRARY FUND, RECEIPTS & PAYMENTS ACCOUNT,

	£	s.	d.
To Balance, 1st January, 1948	21	14	6
	£21	14	6

NATIONAL ILLUMINATION COMMITTEE FUND, RECEIPTS & PAYMENTS

	£	s.	d.
To Balance, 1st January, 1948	381	12	9
,, War Stock Interest	10	10	0
	£392	2	9

INTERNATIONAL ILLUMINATION CONGRESS FUND, RECEIPTS &

	£	s.	d.
To Balance, 1st January, 1947	389	0	6
,, War Stock Interest	10	10	0
,, Copies of Proceedings Sold	2	0	0
	£401	10	6

J. G. HOLMES *(Hon. Treasurer).*

H. C. WESTON *(Hon. Secretary).*

ACCOUNT, FOR THE YEAR ENDED 31st DECEMBER, 1948

	£ s. d.	£ s. d.
By Premiums paid for 1948/49		21 0 0
,, Balance, 31st December, 1947:		
Cash at Bank	6 7 2	
£230 3½ per cent. Registered War Stock at cost	236 13 2	
		243 0 4
		£264 0 4

FOR THE YEAR ENDED 31st DECEMBER, 1948

	£ s. d
By Balance, 31st December, 1947:	
Cash at Bank	21 14 6
	£21 14 6

ACCOUNT, FOR THE YEAR ENDED 31st DECEMBER, 1948

	£ s. d.	£ s. d.
By Expenses of Delegates to Paris Meeting:		85 0 0
Balance, 31st December, 1948:		
Cash at Bank	2 14 3	
£300 3½ per cent. Registered War Stock at cost	304 8 6	
		307 2 9
		£392 2 9

PAYMENTS ACCOUNT, FOR THE YEAR ENDED 31st DECEMBER, 1948

	£ s. d.	£ s. d.
By Balance, 31st December, 1947:		
Cash at Bank	97 2 0	
£300 3½ per cent. Registered War Stock at cost	304 8 6	
		401 10 6
		£401 10 6

We have examined the above accounts with books and vouchers, and certify same to be correct in accordance therewith, and that the Balance Sheet exhibits a true and correct view of the Society's affairs according to the information and explanations given to us.

ROBERT J. WARD & CO., *Chartered Accountants*,
Adelphi Terrace House,
3, Robert Street, Adelphi, W.C.2.

Dated this 16th day of February, 1949.

Polytechnic in London, Birmingham, Cardiff (the second year of the two-year course begun in the previous year), Manchester and the Bootle Technical College, Liverpool. Courses for the Final Grade were arranged at the Northampton and Borough Polytechnics and at Glasgow. During the year 98 students passed the Intermediate Examination, six passed the final section "A," and 20 passed the final section "B."

There are now more facilities for students to take the Final Examinations but they are limited to London and Glasgow, and there are no means whereby students outside these areas who have passed the Intermediate Examination can carry on with their studies for the Final Examination. The Education Committee is studying this matter and hopes, with the assistance of members of the Centres and Groups to arrange for local study groups to be set up to help these students.

Other Activities

The Development Committee, which was set up during 1947, has been active. The standard lecture to school children was made available during the year, and sets of demonstration equipment have been allocated to Centres. Several Centres have taken up this lecture with enthusiasm and, with the active support of the local education authorities, have given lectures at schools in their areas.

The Development Committee has also appointed a sub-committee to look into the preparation of film strips on lighting which will help to further the educational work of the Society.

Financial Position

Expenses have continued to rise, partly due to increased costs and partly to increased activity, and the balance of income over expenditure was smaller than in previous years, in spite of the increased income from subscriptions. The proportion of the subscription income spent on the Transactions, "Light and Lighting" and other publications was over 40 per cent., compared with 36 per cent. in 1947 and 29 per cent. in 1946, and the improved value of the publications was reflected in the increased receipts from sales of reprints, after decreases in recent years. The financial position continues to be satisfactory, but the margin is narrowing, and the increased income must be maintained if the developments are to continue, and if the Society is to subsidise large-scale activities, such as the 1948 summer meeting in the future. The accounts accompanying this report show the detailed figures for the Society's funds and for the fund held for the National Illumination Committee.

Conclusion

The satisfactory conduct of the affairs of the Society during the year reviewed has been due to the diligence and interest of the staff at headquarters, as well as to the voluntary services of the hon. officers of the Society and of the many members who have served on committees of the Council and of local Centres, including the honorary secretaries of Centres of Groups. To all these the Council express their thanks, as well as to authors of papers and those who have served the Society in other ways. The health and progress of every society depends upon the efforts of individual members, and if this principle is generally recognised the further development of the Society's activities will be assured.

J. M. WALDRAM (President).
H. C. WESTON (Hon. Secretary).

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members :—

SUSTAINING MEMBERS :—

Eastern Electricity Board.....*Representative*: G. N. Green.
Finsborough, Stowmarket.

CORPORATE MEMBERS :—

Adamson, W. F. .....14, Chorley Avenue, Castle Bromwich, BIRMINGHAM.
Anderton, L. C. .....20, Osborne Road, Hyde, CHESHIRE.
Atkinson, J. J. .....2, Dene Gardens, Pelaw, GATESHEAD, 10.
Atkinson, W. .....61, Winterbrook Road, Herne Hill, LONDON, S.E.24.
Baker, C. R. .....c.o. Hartley Electromotives, Ltd., 24, Steelhouse Lane, BIRMINGHAM, 14.
Bowey, G. .....19, Kirkheaton Place, NEWCASTLE-ON-TYNE, 5.
Brick, R. .....22, Howard Street, S., Belfast, N. IRELAND.
Campbell, J. D. .....23, Archer Street, Broughty Ferry, DUNDEE.
Denham, S. E. .....c.o. J. Dyson and Co., Ltd., 111, Thornton Road, Bradford, YORKS.
Eats, T. J. D. .....13, Highfield Road, Surbiton, SURREY.
Ferres, T. .....22, Howard Street, S., Belfast, N. IRELAND.
Gaymard, L. .....9, Rue Antoine Bourdelle, Paris (XV^{e}), FRANCE.
Hammond, W. J. .....5, Sandhurst Street, LIVERPOOL, 17.
Lawley, J. G. .....39, Highbridge Road, Wylde Green, Sutton Coldfield, WARWICKS.
Lythgoe, J. .....Vicarage Cottage, Tideswell, DERBYSHIRE.
Moodie, J. K. .....7, Rickleton Avenue, Chester-le-Street, Co. DURHAM.
Morris, R. B. .....44, Pinner Park Gardens, Harrow, MIDDX.
Phillipson, S. M. ....."Welham," 16, Faraday Road, Rugby, WARWICKS.
Pratt, H. .....TI (Group Services) Ltd., Dept. of Development and Research, Plume Street, Aston, BIRMINGHAM, 6.
Reynolds, G. F. .....Craig View, Llangollen, N. WALES.
Richardson, J. D. .....46, Bolbec Road, Fenham, NEWCASTLE-ON-TYNE, 4.
Riddell, R. S. .....20, Friars Walk, Newcastle, STAFFS.
Ross, R. H. .....11, Bruche Avenue, Off Manchester Road, Nr. Warrington, LANCS.
Topping, J. C. .....7, Bank Parade, Preston, LANCS.
Wall, E. .....813, New Hey Road, Outlane, Huddersfield, YORKS.
Watters, W. H. .....76, Orangefield Crescent, Castlereagh Road, Belfast, N. IRELAND.
White, J. .....35, Nelson Street, Bury, LANCS.

Register of Lighting Engineers

The Council have accepted the following applications for inclusion on the Register of Lighting Engineers :—

L. R. Brown, R. J. Cotton, C. H. Earl, P. D. Figgis, B. B. Hayter, J. McFarlane, W. M. McMillan, R. Parker, L. D. Schofield, G. P. Scott, D. A. Strachan, D. L. Tabraham, R. L. M. Tye, A. Wilcock, L. D. White.

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